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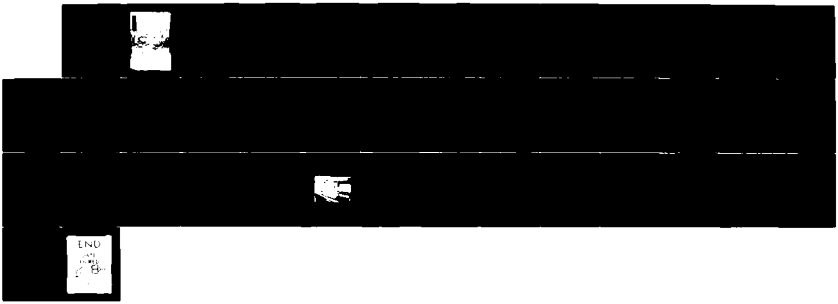

ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 4065

Title: AUTOMATIC PROBER FOR THE DC CHARACTERISATION OF GALLIUM ARSENIDE DEVICES. - PART ONE, THE MEASUREMENT FACILITY

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ABSTRACT

A computer controlled Auto Prober System has been designed and constructed to allow detailed information to be obtained from the large number of Gallium Arsenide (GaAs) devices fabricated in the Microwave Devices Division (DP2). GaAs substrates up to 2 inch diameter can be processed in the DP2 clean room and typical substrates may contain several thousand devices and test patterns. The prober system consists of two separate facilities, one to carry out the DC measurements and the other to allow the data obtained to be analysed and correlated.

This memo describes the measurement facility and gives details of the DC conditions under which the measurements are carried out. A full description of the software is included in this memo and a listing of the software is given in a separate appendix. The data analysis facility is described in RSRE Memorandum 4066.

Both facilities have been designed as an integrated system and offer a range of on wafer measurements which include characterisation of active devices such as GaAs MESFETs (MEtal-Semiconductor Field Effect Transistors) and Schottky diodes as well as measurement routines for use on various test patterns for assessing ohmic contacts and investigating doping profiles of device layers. Passive components such as on wafer capacitors and resistors can be measured.

The system is designed for non-expert use and emphasis has been placed on providing standard measurement routines which can be easily selected from screen menus. Wherever possible flexibility and error trapping have been built into the system.

AUTOMATIC PROBER FOR THE DC CHARACTERISATION OF GALLIUM ARSENIDE DEVICES

PART ONE :- THE MEASUREMENT FACILITY

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AUTOMATIC PROBER FOR THE DC CHARACTERISATION OF GALLIUM ARSENIDE DEVICES

PART ONE :- THE MEASUREMENT FACILITY

This memo describes the measurement and data gathering aspects of the autoprober system in DP2 division. A second memo will describe the data handling and display options available (RSRE Memo 4066).

1) INTRODUCTION

A significant part of the device programme of the Microwave Devices Division is concerned with the technology of Gallium Arsenide (GaAs) device fabrication. In order to assess the technology being developed detailed electrical measurements of devices and standard test patterns form an essential part of this activity.

Work on the autoprober was initiated in March 1985 when it became clear that this device and technology programme would produce GaAs wafers containing many thousands of devices. Manual testing of such large numbers of devices is not feasible as experience of using this approach with small numbers of devices indicated that several weeks would be required to measure and collate the data for a large wafer of MESFETs (MEtal Semiconductor Field Effect Transistors). Limited manual sampling of wafers was not considered a useful option. A computer controlled autoprober would reduce the time required to DC characterise devices and test patterns with the additional advantage that all data would be stored in a computer accessible form enabling histograms, maps or scatter plots to be produced very rapidly.

The prober was originally designed specifically to measure GaAs MESFETs but during the past 18 months the system has been extended to measure diodes and passive components such as resistors and capacitors. A variety of measurement programs are also available for specialised test patterns such as large gate FETs (FATFETs) for Capacitance/Voltage (C/V) profiling and transmission line test patterns for assessing ohmic contacts.

This memo describes the measurement and data gathering aspects of the prober facility and is divided into six sections. Section two outlines the criteria adopted to define the power supply, measuring equipment and computer requirements. Section three describes the hardware used to implement a system to meet the requirements. Section four describes the measurement conditions and gives details of the boundary conditions applying to the various measurements. Section five describes the software used to carry out the measurements and an appendix contains a complete listing of this software.

It should be noted that this prober system is still evolving and the system described represents the situation in March 1987.

2) SYSTEM REQUIREMENTS

The system was initially designed for measuring GaAs MESFETs and the following list of FET parameters formed the original measurement specification (see figure (3)):-

SATURATION CURRENT	Idsso	mA
MUTUAL CONDUCTANCE	gm	mS
PINCH OFF VOLTAGE	Vpinch	V
LOW FIELD RESISTANCE	Rslope	Ohms
OUTPUT CONDUCTANCE	Gd	mS
KNEE VOLTAGE	Vknee	V
GATE LEAKAGE	Igate	uA

An additional list of potential future requirements was also drawn up:-

a) FORWARD DIODE I/V CHARACTERISTICS FOR IDEALITY AND BARRIER HEIGHT MEASUREMENTS ON SCHOTTKY CONTACTS.

b) C/V MEASUREMENTS FOR OBTAINING PROFILES OF DEVICE LAYERS.

c) SPECIFIC CONTACT RESISTANCE MEASUREMENTS ON OHMIC CONTACTS.

d) CAPACITANCE MEASUREMENTS.

e) RESISTANCE MEASUREMENTS.

Consideration of the above lists enabled an estimate of the hardware requirements to be made based on typical expected DC envelopes of the devices and test patterns to be measured. These requirements are summarised below:-

DC PARAMETER	MAXIMUM VALUE	MINIMUM VALUE
CURRENT	1 A, (Power FET?)	1×10^{-9} A, (Gate leakage?)
VOLTAGE	20 V, (10 V probably adequate)	Require 10 mV resolution on power supplies
RESISTANCE	10 M ohm, (Device isolation?)	10 m ohm, (Track resistances?)
CAPACITANCE	100 pF, (MMIC DC blocks?)	50 fF, (Gate capacity?)

The computer hardware and software requirements were also estimated at this stage. A typical 2" diameter wafer with devices pitched at 0.5 mm in both X and Y will contain approximately 8000 devices. If these devices are FETs then at least 8 parameters per device will need to be stored giving a total storage requirement of 64000 items of data. Each item of data is stored as a real number and each real number typically requires 8 bytes for storage so the storage requirement per wafer amounts to 64000 x 8 = 512 Kbytes.

A device such as an FET requires two power supplies for independent control of the drain-source and gate-source voltage. Adding a voltmeter and ammeter per supply, at least one disc drive, a capacitance meter and the prober table requires that the controlling computer be capable of controlling at least 9 peripherals.

The overall speed of the measuring system will be determined mainly by power supply and meter settling times so a moderately fast computer would be adequate to drive the measuring system.

3) PROBING SYSTEM HARDWARE

Initial experience with a system which used the same computer to both gather the data and collate and display it proved unsatisfactory. It quickly became obvious that as much time could be spent examining the data as gathering it and a backlog of wafers waiting to be measured soon built up. At an early stage in the development of the system, therefore, the data sorting, parameter calculation and data presentation functions were separated from the data acquisition and an entirely separate data handling facility incorporating a faster more comprehensive computer was set up. This data handling facility will be described in RSRE Memo No 4066. At the present time the data is gathered on the system described in this memo and stored on 3.5" floppy discs which provide an easily transferable storage medium between the two systems.

The system hardware comprises general laboratory instrumentation, all of the instruments are fitted with an IEEE-488 Standard Interface to allow computer control and data transfer. A brief technical description of the instruments is given below.

Probing computer:- Hewlett Packard Series 86B Computer fitted with advanced programming ROM and extra RAM memory (256Kb). Dual 3.5 inch disc drives (H.P Type 9122D) are used for program (Drive 0) and data (Drive 1) storage. Total storage capability of a single double sided data disc is approximately 0.7 Mb.

Digital Multimeters (DMM):- Keithley Model 195A digital multimeter fitted with DC amps option. The multimeter is a fully programmable instrument with 5.5 digit resolution and is capable of DC voltage measurements between 100 nV - 1000 V on six ranges; 2/4 terminal resistance measurements between 100uohm - 20 Mohm on seven ranges; DC current measurements between 100 pA - 2A on six ranges. At the time of writing this memo, an additional digital multimeter has been incorporated into the system for future use. This multimeter is a Keithley Model 196 digital multimeter which offers all of the facilities of the Keithley Model 195A at 6.5 digit resolution.

Power Supplies:- Hewlett Packard Model 6002A, a general laboratory type power supply which can provide 200 Watts of DC output from 20 V, 10A to 50 V, 4A. The output is completely adjustable and programmable to a resolution of 10 mV.

Automatic Wafer Prober:- Teledyne Tac PR-53, this prober offers a full 6 inch X&Y travel and a steppable resolution of 0.0005 inch in imperial mode or 10 microns in metric mode. At present manually settable probes are fitted. Each probe is fully adjustable in X, Y & Z as this offers a greater versatility than a fixed probe card system when a variety of pad layouts are to be measured. A feature of this prober is its random access capability whereby the prober can be moved to a specific device location and then commanded to step around within the confines of that device before moving to the next device location.

LCR Meter:- Hewlett Packard Type 4275A, this is a fully automatic test instrument designed to measure various impedance elements at frequencies up to 10 MHz. At present the instrument is mainly used to measure capacitance to a resolution of 0.01 fF. Stray capacitance up to 20 pF can be automatically compensated for by the inbuilt automatic zero offset capability of the instrument.

Current Source:- Keithley Type 220, this unit provides DC currents from $\pm$ 0.5 pA to $\pm$ 101 mA. It is a fully programmable instrument with step sizes of 500 fA on the 1 nA range to 50 uA on the 100 mA range. A Bipolar voltage limit of 1 to 105 Volts in 1 V steps can be externally programmed.

Switching System:- Racal-Dana Series 1200, this unit provides selective channel relay switching via the computer. At present 20 channels are used out of a possible 50.

The instruments described above are configured so that, wherever possible, true 4 probe measurements can be carried out. No manual cable changes are necessary as the switch box automatically connects the correct power supplies and voltmeters to the required probes. A photograph of the assembled measuring system is shown in Fig (1) and a circuit diagram is given in Fig (2).

4) MEASUREMENT DETAILS

a) GENERAL

Before probing can start the auto prober probe head has to be aligned to the device array on the wafer. The X and Y tracking and the probe overdrive pressure must also be set up. The auto prober table internal controller requires details of X and Y device pitches and a start or reference point before overall control is handed over, via "command" mode, to the main controlling and data gathering computer.

The type of measurement required is selected from a menu displayed on the main computer Visual Display Unit (VDU) and a series of prompts then lead the operator through the procedure required to identify and create suitable data files on the data storage disc. Options are available which allow a sample of devices to be measured if 100% testing is not required. Where devices are individually numbered the start co-ordinates can be stored allowing correct labelling of any data maps subsequently produced. Once a probing run has started it can be aborted at any time, the data file associated with the particular run being automatically deleted.

b) RESISTANCE

MEASUREMENT CONDITIONS

Keithley 195A digital multimeter used in standard four probe configuration (fig 5), 2000 Ohm range selected, 10 milliohm resolution. The test current driven through the structure being measured has a maximum value of 2 mA with a maximum applied voltage of 2 V.

DEFAULT FAILURE LIMITS

Short circuit defined as less than 0.5 Ohm.

Open circuit defined as greater than 1000 Ohm.

USER SELECTED LIMITS

The open and short circuit limits can be redefined in the range 0 ohms to 1000 ohms.

NOTES ON MEASUREMENT

Multiple resistance measurements on a plain gold plated surface gave a mean resistance of 13 milli-ohms with an associated standard deviation of 5 milli-ohms.

c) CAPACITANCE

MEASUREMENT CONDITIONS

Hewlett Packard 4275A LCR Meter used in parallel mode, capacitance and conductance measured (fig 7). The AC bias level is set at 0.01 V and the usual measurement frequency is 1 MHz.

DEFAULT FAILURE LIMITS

Short circuit defined as > .01 mS conductance. Capacitance fail if measured Capacity < .01 pF.

USER SELECTED LIMITS

Short circuit fail selectable in range 1 nS to 10 S.

Capacitance fail limit selectable down to 0.1 fF.

NOTES ON MEASUREMENT

This measurement is not a true 4 probe measurement as the high-low test leads are joined at the top of the probe holders and two probes only are used to connect to the structure being measured on the wafer. A parasitic series resistance due to the probe tip-test structure contact resistance is, therefore, always present unless care is taken to zero it out prior to a measurement run. Stray capacity of probes and leads can be "zeroed out" to less than 1 fF with the probes raised. The measurement frequency can be preselected in the range 10 KHz to 10 MHz.

d) FIELD EFFECT TRANSISTORS

The sequence in which the device parameters are measured required a considerable amount of thought as the requirement was to minimise the power supply and DVM settling time overheads whilst at the same time performing the measurements in a logical sequence. The sequence chosen should enable the maximum amount of data to be obtained even from poor or incomplete FETs, ie gm or pinch off readings are meaningless on devices without gates but Rslope and Idsso values could be obtained provided that the lack of a gate was also indicated.

The device data is stored in a multiple element array, the position of the data in this array corresponds to the parameter it relates to. The number of individual arrays corresponds to the number of devices probed on the wafer.

Pass/fail limits were set for every parameter to indicate gross defects in the device (no gates, short circuits etc) and detection of these is indicated by storing an appropriate token in the specific parameter position in the array containing the measured device data.

FET MEASUREMENT SEQUENCE

Figure 3 identifies the parameters measured ie. Rslope, Gd, gm etc and the measurement sequence is shown diagrammatically in Figure 4. The measurements are described, in the correct sequence, in this section. The measuring circuit is shown in fig (6).

i) TEST FOR OFF WAFER

The computer interrogates the probe table edge detector and if "off wafer" is returned then all the elements of the device parameter array are set to -3 and the probe table is commanded to step to the next device.

ii) Rslope (At 0.2 V)

MEASUREMENT CONDITIONS

Set Vgs = 0 V
Set Vds = 0.2 V
Read Ids

FAILURE LIMITS

Open circuit fail if Rslope > user selected upper limit.
Short circuit fail if Rslope < user selected lower limit.

USER SELECTED LIMITS

Upper limit selectable in range 1 to 1000 Ohms (Default = 500 Ohms).
Lower limit selectable in range 1 to 500 Ohms (Default = 1 Ohm).

FAIL INDICATORS

If Rslope open circuit store -6 in all array elements.
If Rslope short circuit store -2 in all array elements.

NOTES ON MEASUREMENT

The value of Vds (0.2 V) was chosen to give easily measurable values of Ids and was judged to be sufficiently remote from the expected device knee voltage.

iii) Idsso (At Vds = 5 V)

MEASUREMENT CONDITIONS

Set Vgs = 0 V
Set Vds = 2 V
Read Ids (2 V)
Set Vds = 5 V
Read Ids (5 V).

FAILURE LIMITS

If Idsso > upper limit then Idsso fail.

USER SELECTED LIMITS

Upper limit selectable in range 1 to 200 mA. (Default 200 mA).

FAIL INDICATOR

If Idsso fail then store -9 in Idsso and Vpinch array elements.

NOTES ON MEASUREMENT

The actual measurement sequence is slightly different to that implied in this written sequence. After Rslope has been calculated Vds is set to 2 V and Ids (2 V) is read, Vds is then set to 5 V and Ids (5 V) is read, Ids (5 V) is defined as Idsso. Ids (2 V) and Ids (5 V) are used in the calculation of Gd.

The Vds power supply is preset to limit at approximately 220 mA in order to prevent possible damage to the probe tips or device under test.

iv) Gd [(Ids (5 V)-Ids (2 V)]/(5-2)

MEASUREMENT CONDITIONS

Vgs = 0 V
Set Vds = 2 V
Read Ids (2 V)
Set Vds = 5 V
Read Ids (5 V)
(See Idsso measurement)

FAILURE LIMITS

Gd fail if Gd > 10 mS.

USER SELECTED LIMITS

Not available

FAIL INDICATOR

If Gd fail then store -13 in Gd and Vpinch array elements.

NOTES ON MEASUREMENT

As described in the section on Idsso the values for Ids (2 V) and Ids (5 V) are used to obtain Gd. Vds values of 2 V and 5 V were chosen in order to give distinctly different readings of Ids, it should be noted that a Gd value of 1 mS corresponds to an Ids difference of only 3 mA between the Ids values at 2 V and 5 V. The upper Vds limit of 5 V was selected to give the same bias conditions as the RF measurements and to be similar to the actual DC operating voltages of typical RF amplifier circuits.

If the device is oscillating during testing or if thermal effects occur they usually manifest themselves as a "droop" in the Vds/Ids curve above saturation. Setting Gd = 0 is used to indicate whether these effects are taking place, a check with the manual prober will help to isolate the actual fail mechanism.

v) <u>Vknee</u> (Intercept of Gd and Rslope)

MEASUREMENT CONDITIONS

See Rslope, Idsso and Gd

FAILURE LIMITS

If Vknee > 3 V then Vknee fail.

USER SELECTED LIMITS

Not available.

FAIL INDICATOR

If Vknee fail then store -7 in Vknee and Vpinch array elements.

NOTES ON MEASUREMENT

Vknee is defined as the intercept of Gd and Rslope as this appeared to be the most consistent way of obtaining an estimate of this parameter. Comments on the precision of the Gd measurement also apply to Vknee.

vi) <u>gm</u> (Vds = 5V)

MEASUREMENT CONDITIONS

Set Vgs = -0.5 V
Set Vds = 5V
Read Ids

FAILURE LIMITS

gm fail if gm < lower limit.

USER SELECTED LIMITS

Lower limit selectable down to 0.2 mS. (Default = 0.2 mS).

FAIL INDICATOR

If gm fails then store -5 in gm and Vpinch array elements.

NOTES ON MEASUREMENT

gm is defined as [Idsso - Ids(Vgs = -0.5 V)] x 2 mS. It is appreciated that in general a larger value for gm can be obtained for small values of Vgs and smaller values for gm can be obtained for larger values of Vgs. The value obtained for a Vgs swing of 0 V to 0.5 V is considered a good compromise.

vii) Igate (Vgs = -4 V)

MEASUREMENT CONDITIONS

Set Vgs = user selectable. (default = -4 V)
Set Vds = 0 V
Read Igs

FAILURE LIMITS

Igate fail if Igs > upper limit.

USER SELECTED LIMITS

Upper limit selectable up to 100 microamps. (Default 100 microamps).
Vgs selectable in range 0 to -5 V. (Default -4 V).

FAIL INDICATOR

If Igate fail then store -4 in Igate and Vpinch array elements.

NOTES ON MEASUREMENT

A large default value is allowed for Igs so that subsequent parameters will be measured.

viii) Idss4 (At Vds = 5V)

MEASUREMENT CONDITIONS

Set Vgs = user selectable in range 0 to 5 V (Default -4 V)
Set Vds = 5 V.
Read Ids.

FAILURE LIMITS

None.

FAIL INDICATOR

If Idss4 > Ids (pinch off) then store Idss4 value and enter -8 in Vpinch.

NB. The parameter Ids (pinch off) is defined in the following, "Vpinch" section.

NOTES ON MEASUREMENTS

This parameter enables an estimate to be made of the extent to which a device has failed to pinch off, ie if the pinch off level is set to Ids < 1 ma, Idss4 will show whether a failed device bottomed at 1.1 ma or 110 ma.

The value of Idss4 is used to determine if the device can be pinched off, if Idss4 > Ids (pinch off) then a "failed pinch off" token is stored in the Vpinch array element and the probe table is moved on to the next device. The value of Idss4 is of course always stored in the Idss4 array element.

ix) Vpinch (Vds = 5V)

MEASUREMENT CONDITIONS

Set Vds = 5V.
Step Vgs from maximum reverse bias up to 0 V
Read Ids

FAILURE LIMITS

Vpinch fail if Ids > Ids (pinch off) and Vgs = Vgs maximum.

USER SELECTED LIMITS

Ids (pinch off) selectable from 10 microamps to 200 mA. (Default = 1 mA).
Vgs maximum selectable from 0 V to -5 V.

FAIL INDICATOR

If Vpinch fail then store -8 in Vpinch array element.

NOTES ON MEASUREMENT

The previous measurement (Idss4) was carried out with Vgs set to the maximum negative value. The pinch off measurement continues on from this by reducing the reverse bias on the gate in 1 V steps and monitors Ids after every step. When Ids becomes greater than Ids (pinch off) the voltage on the gate is made more negative in 0.1 V steps until Ids is again below Ids (pinch off). The gate voltage at which this occurs is defined as the pinch off voltage, it should be noted that Vpinch is quantised in multiples of 0.1 V.

e) CAPACITANCE-VOLTAGE PROFILING

Two measurement options are available:-

i) MEASUREMENTS ON A LARGE GATE FET TEST PATTERN

(FATFET).

ii) MEASUREMENTS USING A STANDARD MERCURY PROBE.

i) <u>MEASUREMENTS ON A LARGE GATE FET TEST PATTERN (FATFET)</u>

One of the standard test patterns incorporated into a number of mask sets consists of a 150 micron X 100 micron Schottky contact fabricated on a mesa adjacent to an ohmic contact. This test pattern is used for obtaining doping profile information on the FET channel layer and is known as a "FATFET".

<u>MEASUREMENT CONDITIONS</u>

The LCR Meter type 4275A is used in the parallel mode and readings of capacitance and conductance are made at each bias level. The amplitude of the AC measuring voltage is set to .01 V and the usual measurement frequency is 1 MHz. The DC bias polarity is automatically sensed and the DC reverse bias is stepped in 0.1 V increments up to a maximum of 9 V. The measurement circuit is shown in fig (7).

<u>DEFAULT FAILURE LIMITS</u>

The measurement cycle of an individual test pattern is terminated if any one of the following conditions occurs.

a) If the measured capacity falls below 0.5 pF.

b) If the measured capacity remains unchanged for two consecutive bias levels.

c) If the conductance exceeds .01 mS.

<u>USER SELECTED LIMITS</u>

The value at which the measurement is terminated can be reduced from 0.5 pF to 0.1 fF.

<u>NOTES ON MEASUREMENT</u>

Zero bias capacities of 20 pF to 40 pF can occur on typical test patterns and the 0.5 pF default limit condition was chosen on the basis of this. The LCR meter internal DC bias supply has a limited current capability and the .01 mS conductance limit is present to prevent anomalous readings due to poor power supply regulation, the actual values of DC bias are read using an external meter. The measurement frequency can be preselected in the range 10 KHz to 10 MHz.

A series of test runs on Schottky contacts of different areas on the same substrate gave excellent consistency in the calculated N_D values when allowance for the different areas was made. The results of this test also gave very good agreement with N_D values obtained using a conventional mercury probe in the materials assessment section of DP2.

ii) MEASUREMENTS USING A STANDARD MERCURY PROBE

MEASUREMENT CONDITIONS

Owing to the larger Schottky contact area the zero bias capacity is much greater than in the FATFET measurement. All other measurement conditions are the same as in the FATFET case.

FAILURE LIMITS

As FATFET.

USER SELECTED LIMITS

As FATFET.

NOTES ON MEASUREMENT

To avoid errors due to excess stray capacity the LCR measurement leads are not automatically switched via the relay box. The changeover from FATFET to mercury probe requires manual connection of the appropriate measuring terminal. (See also "CAPACITANCE").

f) TRANSMISSION LINE OHMIC TEST PATTERN

MEASUREMENT CONDITIONS

Keithley model 195A digital multimeter used in standard 4 probe configuration,2000 Ohm range selected, 10 milli-ohm resolution. The measurement circuit is shown in fig (5).

DEFAULT FAILURE LIMITS

Short circuit defined as < 0.5 Ohms.

Open circuit defined as > 1000 Ohms.

USER SELECTED LIMITS

Short circuit limit selectable in range 0 Ohms to 1000 Ohms.

NOTES ON MEASUREMENT

The standard test pattern consists of 5 ohmic pads, each 100 micron square, with gaps of 20 microns, 15 microns, 10 microns and 5 microns between consecutive pads. The array of pads is fabricated on a 100 micron wide mesa.

During probing the table automatically steps along the mesa sequentially measuring each gap in a field before moving on to the next test pattern field. The preset pad to pad incremental steps are made in the vertical (Y) direction and the wafer should be aligned with the interpad gaps horizontal and the widest gap at the bottom of the field.

g) DETAILED FET I/V CHARACTERISTICS

This measurement option allows the Vds/Ids characteristics of a FET to be measured in much more detail than the standard autoprobe program. The data gathered is in a readily accessible form for computer curve fitting and subsequent device modelling. The measurement sequence consists of two parts, firstly a standard rapid device measurement as described in part d) of this section and secondly the Ids/Vds characteristics of the device are fully mapped for various values of Vgs.

To obtain the detailed characteristics the Vds and Vgs voltages are incremented in small steps (typically 0.1 V) and the corresponding values of Ids are recorded. A full measurement of this type is very time consuming and is usually only carried out on individual devices which are being investigated in detail.

MEASUREMENT CONDITIONS

As under 'FIELD EFFECT TRANSISTORS'.

The Vds and Vgs voltages can be stepped in increments of 0.1 V to 1.0 V.

DEFAULT FAILURE LIMITS

As under 'FIELD EFFECT TRANSISTORS'.

NOTES ON MEASUREMENT

During the detailed measurement sequence the normal Ids (pinch off) value of 1 mA does not apply, a value of Ids (pinch off) of 0.1 mA is substituted instead.

h) FORWARD DIODE I/V CHARACTERISTICS

This measurement can be carried out on the "FATFET" test pattern and provides a means of monitoring the quality of the Schottky contact technology.

MEASUREMENT CONDITIONS

A constant current source is used to provide forward diode current over the range 10^{-9} A to 0.1 A. The diode forward voltage at each current level is recorded. The measurement circuit is shown in fig (8).

DEFAULT FAILURE LIMITS

The measurement cycle of an individual test pattern is terminated if the forward voltage drop exceeds 3 V.

USER SELECTED LIMITS

Maximum diode current selectable in range .001 A to 0.1 A.

NOTES ON MEASUREMENT

In addition to using this measurement as a process monitor on FATFETs the measurement can be used to determine the series resistance of any Schottky diode. Caution should be exercised in determining the maximum forward current to be passed through fine geometry structures.

5) SYSTEM SOFTWARE DESCRIPTION

i) GENERAL

When the computer is switched on a program file named (AUTOST) is automatically loaded from the program disc resident in disc drive '0'. When loaded this program prompts the operator to enter the time and date into the H.P 86 computer which then automatically loads a program file called (MENU). As the name implies this program graphically displays the program options available to the operator. At present these options are:-

Softkey k1) AUTOMATIC OHMIC PROBING
Softkey k2) AUTOMATIC FET PROBING
Softkey k3) AUTOMATIC CAPACITANCE PROBING
Softkey k4) FATFET C/V PROFILE PROBING
Softkey k5) TRANSMISSION LINE OHMICS
Softkey k6) PROBER SETTING UP INSTRUCTIONS
Softkey k7) VIEW DATA DISC DIRECTORY
Softkey k8) DETAILED FET V/I CHARACTERISTIC
Softkey k9) MERCURY PROBE C/V PROFILER
Softkey k10) DIODE FORWARD I/V CHARACTERISATION

Softkey k11-k13) UNUSED AT PRESENT
Softkey k14) ERASE ALL DISC DATA

Selection of one of the above options automatically loads and runs the appropriate program file. All the measurement programs consist of two parts. The first part allows variables such as wafer name, wafer size etc, to be entered. The second part carries out the measurement and data storage. The following description is applicable to all the probing programs.

The programs start with a menu display with the softkeys defined as follows:-

k1) START PROBING
k4) CHANGE DEFAULT LIMITS
k5) ENTER DATA
k14) RETURN TO MENU

Before probing can be started the operator must first enter data by selecting softkey k5) which calls a subroutine [Colrows]. This subroutine prompts the operator to enter the relevant probing data required by the software ie number of device columns, number of device rows, number of device pitches per step in 'X', number of device pitches per step in 'Y', starting device number and information for a directory. The directory file stores a description of up to 50 characters and the operators initials.

Each data disc contains a directory which is a data file called [DIRECTORY]. Each data file holds 15 records of 80 characters and is formatted as shown:-

Characters [1, 2] = Record number.
Characters [3, 12] = Name of data file.
Characters [13, 13] = Type of file ie, 'F' for FET data etc.
Characters [14, 64] = File description of up to fifty characters.
Characters [65, 72] = Date of probing.
Characters [73, 75] = Operators initials, up to three characters.
Characters [76, 77] = Used to hold the number of completed entries in the directory. Applicable to record 1 in the directory only.

From the number of columns and rows and the device pitches per step information a data file of the required size can be created eg COLUMNS = 40 ROWS = 20, NUMBER OF DEVICE PITCHES PER STEP IN X&Y = 1, tells the computer that every device in a 40*20 array is to be measured ie, 800 devices (40*20). For example a FET record consists of 15 Real numbers, each of which requires 8 bytes of data storage ie, 8*15 = 120 bytes per record. A data file is then created in this example as 800+4 (804) records at 120 bytes each. The extra 4 records are added to include the number of columns variable 'Xcol', number of rows variable 'Yrow', number of steps in X 'Xstep', number of steps in Y 'Ystep', default pass/fail limits 'L1-Ln', x original 'Xorg', y original 'Yorg', default pass/fail limits 'L1-L8', maximum values for each parameter "MX", minimum values for each parameter "MI", passes "P", X device number "XDEVN", Y device number "YDEVN", and off wafer "OFFW". The number of columns and rows will be modified if device pitches per step greater than 1 have been entered. The variables 'Arrysizex', 'Arrysizey' show this modification in the program listings. The originally entered column and row values are preserved in the data as x original "XORG" and y original "YORG". The structure of the data files varies depending on the measurement that has been selected and full descriptions are given later in this memo under the relevant program headings.

The subroutine [Colrows] also carries out the following tasks:-

a) Initializing the data disc, if required.
b) Checking sufficient storage space exists on the disc for each new data file.
c) Reading or creating a data file called [Directory].
d) Error trapping eg duplicate data filename on the data disc, checking rows and columns are integers.

Selecting softkey k4) from the menu display enables the default measurement limits to be changed. To change the limits a subprogram is automatically called and executed. The details of the limit changing subprograms are given later in this memo under the relevant program headings. The subprograms display the measurement default values and a table of the changed default values. The softkeys are used to select and change a limit. When a new limit is entered it is checked against absolute limits before it is accepted. Selection of softkey k14) returns the operator to the probing program.

Selecting softkey k1) from the program menu display initiates the automatic probing cycle. A display of the selected measurement parameters is shown together with the number of device rows, device columns, and chosen data file name. The operator has the option of restarting the program if there is an error in this information. The programme continues with a prompt to remind the operator to check that the moving prober table is clear of obstructions. Probing starts on pressing softkey k1) which initialises variables and sets up the instrumentation via the IEEE Interface. Record 1 is stored on the data disc and the program enters a double loop determined by the number of device rows and device columns to be probed. The loop drives the prober table up the first column, down the second column, up the third column etc. At each measurement point the prober table is raised and the prober status is checked to detect the prober edge sensor status. If the prober status word string STAS[1,2]=30 then an offwafer is detected. If the prober edge sensor is offwafer the value '-3' is assigned to the measurement variables, the prober table is lowered and moved to the next device. The following subroutines [Proberstatus], [Tableup], [Tabledwn], [Tablexmov], [Tableymov] are used in all the probing programs to control the wafer prober. As the subroutine names imply they read the prober status word; raise the prober table up; lower the prober table down; move the prober table in 'X' direction; move the prober table in the 'Y' direction.

If an offwafer is not detected then an appropriate measurement subroutine is called and the device measurement is performed before proceeding to the next device. The prober table is always lowered before it is moved to another device. The data for each device is stored after each individual device measurement. When the measurements are completed the data file is closed and the directory is updated to include the data file information previously entered in subroutine [Colrows]. The power supplies are set to zero volts, all relays opened and instrumentation cleared via the IEEE Interface. The program then automatically loads and returns to the (MENU) program.

The following is a list of the common subroutines used in all the probing programs together with a brief description:-

[Setdvmdisplay]:- Restores the DMM display to normal operation if the display has been used to display an ASCII message.
[Setscreen]:- Sets the HP 86 to graphall mode and displays the program title, date, etc.
[Proginstr]:- Displays the program instructions.
[Labelkey]:- Displays boxes to label the softkeys.
[Proberfault]:- Called if the automatic wafer prober has not been set to command mode.

ii) <u>k1) AUTOMATIC OHMIC PROBING PROGRAM FILE (OHMPROBE)</u>

The hardware is configured as shown in figure (5).

DMM (720) ----- IEEE 720 SET TO 2K OHM RANGE
DEFAULT LIMITS SHORT :-0.5 OHM
OPEN :-500 OHM
ABSOLUTE LIMITS SUBPROGRAM [OHM LIMITS]:- 0<SHORT<1000
0<OPEN <1000

In the program listing the measuring subroutine is called [Ohmmeasure]. The resistance measurement is entered in subroutine [Readohm], Line 1910, and the value placed in variable 'Ohmr'. This value is then checked against the default limits. If the value is greater than the default open circuit limit it is re-measured to double check the reading. The ohmic data is stored in data files of the format shown below which are designated type 'S' data files.

FORMAT OF OHMIC DATA FILE:-
1st record:- XCOL, YROW, XSTEP, YSTEP, XDEVN, YDEVN, 0, -9..
2nd record:- L1, L2, 0, 0, 0, XORG, YORG, -999
3rd record:- MX, MI, 0, 0, 0, 0, 0, -999
4th record:- 0, 0, 0, 0, 0, 0, 0, -999
5th record:- OHMR, 0, 0, 0, 0, 0, 0, -999
6th record to Nth record same format as 5th record

Note:- Variable OHMR is the measured ohmic value.

iii) k2) AUTOMATIC FET PROBING PROGRAM FILE (FETPROBE)

The hardware is configured as shown in figure (6).

```
DMM(720) ----- IEEE 720 SET TO 20 VOLT RANGE
DMM(717) ----- IEEE 717 SET TO 200 mA RANGE
DMM(718) ----- IEEE 718 SET TO 200 uA
DEFAULT LIMITS SHORT :-1 OHM
               VKNEE :-3 V
               RSLOPE:-500 OHM
               IDSSO :-200 mA
               Gm    :-0.2 mS
               IGATE :-100 uA
               VIDS  :-1 mA
               VGATE :-4 V

ABSOLUTE LIMITS SUBPROGRAM [FETLIMITS] :- 0.1<SHORT OHM
                                          0<VKNEE <3 V
                                          0<RSLOPE<1000 OHM
                                          0<IDSSO <200 mA
                                          0<Gm
                                          0<IGATE <200 uA
                                          0<VIDS  <200 mA
                                          0<VGATE <5 V
```

In the program listing the FET measuring subroutine is called [Fetmeasure], Line 1870. All variables are initialized with the value '-55'. Assuming a device is not offwafer, power supply (715) is set to 0.2 V. Power supply (713) is set at 0 V. This applies 0.2 V between the FET drain and source pads with zero bias on the gate. The source-drain current is then measured by DMM (717) and the source-drain voltage by DMM (720); readings are normalized by multiplying by 1000. If the current reading is less than 0.02 mA ie, 'Rslope' is greater than 10 KOhm, then a failure value of '-6' is assigned ie, device open circuit. This check, for values greater than 10 KOhm always operates regardless of any 'Rslope' limits selected. The variable 'Rslope" is calculated and checked against default limits. If 'Rslope' is greater than the 'Rslope' default limit then a failure value of '-6' is assigned. If 'Rslope' is less than the short default limit then a failure value '-2' is assigned.

If a failure is assigned to a reading the measurement cycle is aborted at program line [Finis] where the prober table is lowered and both power supplies set to zero volts by subroutine [Setzerovolt], Line 2830.

On satisfactory completion of the 'Rslope' test, power supply (715) is set to 2 V and the source-drain voltage measured by

DMM (720); the source-drain current is then measured by DMM (717). The voltage value is placed in variable 'Volt2' and the current value is placed in variable 'Ids2'. Power supply (715) is then set to 5 V and the source-drain voltage and current remeasured. The new voltage value DMM (720) is placed in variable 'Volt5'; the current value DMM (717) in variable 'Ids5'. The current variable 'Ids5' is defined as 'Idss0' and is checked against the 'Idss0' default limit. A failure value of '-9' is assigned to an 'Idss0' fail.

The next few lines of program, Lines 2190 to 2310 calculate the output conductance 'Gd' and Knee voltage 'Vknee'. The 'Gd' failure conditions and 'Vknee' calculation are found in lines 2200 to 2310; a 'Vknee' failure is given the value '-7'.

Power supply (713) is now set to give -0.5 V on the FET gate. The source-drain current reading is taken by DMM (717) and the 'Gm' calculated (Line 2370). A 'Gm' failure is given the value '-5'. Both the power supplies are returned to zero volts before power supply (713) is set to give -4 V on the FET gate. The FET gate current, variable 'Igate', is now measured by DMM (718). The value '-4' is given to an 'Igate' failure. Power supply (715) is now set to give 5 V between the FET drain and source pads and the source-drain current measured on DMM (717) is entered as variable 'Idss4'.

If 'Idss4' is greater than the default 'Vidslim' limit a 'Vpinch' failure of '-8' is assigned. If 'Idss4' is less than 'Vidslim' then the program starts the 'Vpinch' measurement.

The 'Vpinch' measurement occurs on lines 2590 to 2680 and uses subroutine [Vpinchvolt] to set the gate-source voltage supply (713) and DMM (717) to measure the source drain current 'Ipinch'. Coarse voltage increments (1 volt steps) are used first to roughly determine the gate voltage either side of pinch off, Line 2610 checks for 'Ipinch' greater than the default 'Vidslim' limit. If 'Ipinch' exceeds 'Vidslim' an additional routine is entered which steps the gate voltage more negative in 0.1 V increments until 'Ipinch' is less than 'Vidslim'. This value of gate voltage is called the pinch-off voltage and is stored in the variable 'Vpinch'. It should be noted that 'Vpinch' is only measured to the nearest 0.1 V. This value was selected to help speed up the measurement. Program Lines 2640 to 2680 control the fine 0.1 V steps and determine the pinch off voltage. If this control loop reaches 4 V without achieving pinch-off then a failure value '-8' is assigned to the variable 'Vpinch'.

If the pinch-off measurement is successful the program executes subroutine [Charactcurve] before storing the data and continuing with the next measurement. It should be noted that the 'Vpinch' variable is always used to store the failure mode of the device under test. Storing all the failure information in the 'Vpinch' data slot enables failure maps to be produced easily and rapidly.

Subroutine [Charactcurve] is used to draw a simplified characteristic curve on the computer display monitor screen if the FET under test has passed all the standard tests. The FET data is stored in data files of the format shown below which are designated type 'F' data files.

FORMAT OF FET DATA FILE:-

1st record:- XCOL, YROW, XSTEP, YSTEP, XORG, YORG, L1, L2, L3, L4, L5, L6, L7, L8, -999
2nd record:- MX_1, MI_1, MX_2, MI_2, MX_3, MI_3, MX_4, MI_4, MX_5, MI_5, 0, 0, 0, 0, -999
3rd record:- MX_6, MI_6, MX_7, MI_7, MX_8, MI_8, P, 0, 0, 0, 0, 0, 0, 0, -999
4th record:- 0, 0, 0, 0, 0, 0, XDEVN, YDEVN, 0, OFFW, 0, 0, 0, 0, -999
5th record:- RSLOPE, IDSSO, IGATE, Gm, VPINCH, IDSS4, VKNEE, Gd, 0, 0, 0, 0, 0, 0, -999
6th record to Nth record same format as 5th record
Note:- 15 Real numbers per record.

iv) k3) AUTOMATIC CAPACITANCE PROBING PROGRAM FILE (CAPPROBE)

The hardware is configured as shown in figure (7).

LCR (712) ----- IEEE 712 SET TO CAPACITANCE
EQUIVALENT PARALLEL CONDUCTANCE MODE
DEFAULT LIMITS LOW LIMIT:- 1 pF
SHORT :- 0.01 mS

ABSOLUTE LIMITS SUBPROGRAM [FETLIMITS] :- 0<LOW LIMIT
0<SHORT

This program utilises the same general structure as the programs previously described. An extra section, Lines 610 on, has been added to allow frequency selection between .01 MHz and 10 MHz. The frequency selected is placed into variable 'Freql' and the LCR Meter (712) is set to the selected measurement frequency.

The capacitance measurement subroutine is called [Capmeasure], Line 2000. After checking for an offwafer condition the LCR Meter (712) is commanded to read the capacitance and conductance. Variable 'Capc' is the measured capacitance; variable 'gCon' is the measured conductance. The capacitance data is stored in data files of the format shown below which are designated type 'C' data files.

FORMAT OF CAPACITANCE DATA FILE:-

1st record:- XCOL, YROW, XORIG, YORIG
2nd record:- L1, L2, FREQ1, -999
3rd record:- MX_1, MX_2, XDEVN, XSTEP
4th record:- MI_1, MI_2, YDEVN, YSTEP
5th record:- CAPC, gCON, 0, -999

6th record to Nth record same format as 5th record
Note:- 4 Real numbers per record.

v) <u>k4) FATFET C/V PROFILE PROBING PROGRAM PROGRAM FILE (CVPROBE)</u>

The hardware is configured as shown in figure (7).

```
DMM (720) ----- IEEE 720 SET TO 20 V RANGE
LCR (712) ----- IEEE 712 SET TO CAPACITANCE
                EQUIVALENT PARALLEL CONDUCTANCE MODE
DEFAULT LIMITS LOW LIMIT:- 5.E-13 pF
               SHORT :- 0.01 mS

ABSOLUTE LIMITS SUBPROGRAM [CAPLIMITS] :- 0<LOW LIMIT
                                          0<SHORT
```

This program is identical to the capacitance probing program file (Capprobe) for selection of the measurement frequency. After a frequency has been selected the program enters a routine called [CheckOsc], Line 1160. This routine checks that the LCR Meter oscillator voltage is set to less than 0.01 V ie, less than 10% of the minimum bias increments. This voltage is read directly from the LCR Meter (712) into the variable 'Volt' and is adjustable from the LCR Meter front panel by a potentiometer. If the oscillator voltage is set greater than 0.01 V then the routine informs the operator that the oscillator level is excessive and will not allow measurements to continue until the voltage has been turned down.

In the main probing loop an additional subroutine called [Setread], Line 2280, is called. This subroutine sets the LCR Meter Bias Voltage and then enters a measurement loop which repeats the measurement a number of times determined by the value of the variable 'Average'. The bias voltage is read by DMM (720) which is connected to the rear bias monitor terminals of the LCR Meter. Capacitance and conductance are stored in the variables 'Capl' and 'Conl'. The bias voltage is stored in variable 'Voltl'. On completion of the loop the sums of the measured variables are divided by the variable 'Average' to give the average measurement readings of the voltage, capacitance and conductance. These readings are stored in the variables 'Volt', 'Cap' and 'Con' respectively.

At the start of every device measurement, subroutine [Setread] is called with the variable 'Bias' set to 0 V and 'Average' set to 5. 'Bias' is then set to +0.5 V and the measurement is repeated. From these two readings it can be automatically determined whether the bias increments should be positive or negative, assuming only 'N' layers are being measured. The measurement continues with 'Average' set to 2 before the main measurement subroutine [Cvmeasure], Line 1960 is called.

Subroutine [Cvmeasure] first checks the offwafer status as in previous probing programs and then enters a loop which increments the bias voltage from 0 V to 9.5 V in 0.1 V increments. Subroutine [Setread] is called within the loop until either the loop is completed or the capacitance and conductance exceed the default limits. Offwafer is stored as '-3' in the first voltage position of the data file whilst null data is stored as '-55'. The capacitance and voltage data are stored in data files of the format shown below which are designated type 'P' data files.

FORMAT OF C/V DATA FILE:-
1st record:- XCOL, YROW, CAPLIM, CONLIM, XDEVN, YDEVN, XSTEP, YSTEP, XORIG, YORIG, FREQ1 ------------- 0, 0, 0, -999
2nd record:- V_1, C_1, V_2, C_2, V_3, C_3, V_4, C_4 -------------- Vn, Cn, -999
3rd record to Nth record same format as 2nd record
Note:- The length of each record is 192 real numbers.
'V' = Voltage 'C' = Capacitance

vi) <u>k5) AUTOMATIC TRANSMISSION LINE OHMIC PROBING PROGRAM FILE (TRANSPROBE)</u>

The hardware is configured as shown in figure (5).

DMM (720) ----- IEEE 720 SET TO 2K OHM RANGE
DEFAULT LIMITS SHORT :- 0.5 OHM
OPEN :- 500 OHM
ABSOLUTE LIMITS SUBPROGRAM [OHMLIMITS] :- 0<SHORT<1000
0<OPEN <1000

In the program listing the measuring subroutine is called [Ohmmeasure], Line 1690. The resistance measurement is entered in subroutine [Readohm], Line 2400, and the measured value placed in variable 'Ohmr'. This value is then checked against the default limits. If the measured value is greater than the default open circuit limit it is re-measured to double check the measurement.

The first measured value of resistance obtained in the variable 'Ohmr' is the transmission line 20 Micron Gap. The program then utilises the incremental stepping feature of the prober and increments to the next gap to be measured which is the 15 Micron Gap. To perform the movement increment two additional prober subroutines are called in this program. The first subroutine [Tableincup], line 1670, increments the table by the string variable 'YstpupS'. The second subroutine [Tableyincdwn], Line 1680, increments the prober table in the opposite direction by the amount held in string variable 'YstpdwnS'. The default step up and step down values for the two string variables can be found in Line 810.

On completion of the 15 micron gap resistance measurement the prober table increments to the next gap to be measured. The sequence is repeated until the last gap ie, 5 micron gap, has been measured. The prober table is then incremented back down to the 20 micron gap using subroutine [Tableydwn] so that the prober table is ready to step to the 20 micron gap in next device field. Before stepping to the next device the measured resistance values stored in variable array 'Ohm' are transferred onto the disc data file. The data files are of the format shown below which are designated type 'R" data files.

```
FORMAT OF TRANSMISSION LINE OHMIC DATA FILE:-
1st record:- XCOL, YROW, XSTEP, YSTEP, XDEVN, YDEVN, 0, -999
2nd record:- L1, L2, 0, 0, 0, XORG, YORG, -999
3rd record:- MX, MI, MX, MI, MX, MI, 0, -999
4th record:- MX, MI, 0, 0, 0, 0, 0, -999
5th record:- OHM1, OHM2, OHM3, OHM4, 0, 0, 0, -999
6th record to Nth record same format as 5th record
   Note:- Variable OHM1 = MEASURED 20 MICRON GAP OHMIC VALUE
                   OHM2 = MEASURED 15 MICRON GAP OHMIC VALUE
                   OHM3 = MEASURED 10 MICRON GAP OHMIC VALUE
                   OHM4 = MEASURED  5 MICRON GAP OHMIC VALUE
```

vii) k8) DETAILED FET V/I CHARACTERISTIC PROGRAM FILE (VIPROBE)

The hardware is configured as shown in figure (6).

```
DMM(720) ----- IEEE 720 SET TO 20 VOLT RANGE
DMM(717) ----- IEEE 717 SET TO 200 mA RANGE
DMM(718) ----- IEEE 718 SET TO 200 uA RANGE
DEFAULT LIMITS SHORT :-1 OHM
               VKNEE :-3 V
               RSLOPE:-500 OHM
               IDSSO :-200 mA
               Gm    :-0.2 mS
               IGATE :-100 uA
               VIDS  :-1 mA
               VGATE :-4 V

ABSOLUTE LIMITS SUBPROGRAM [FETLIMITS] :- 0.1<SHORT OHM
                                          0<VKNEE <3 V
                                          0<RSLOPE<1000 OHM
                                          0<IDSSO <200 mA
                                          0<Gm
                                          0<IGATE <200 uA
                                          0<VIDS  <200 mA
                                          0<VGATE <5 V
```

The structure of the program is identical to the FET probing program file (Fetprobe) except no prober table movements are incorporated. Commands to raise and lower the prober table are retained.

The measurement sequence starts by calling the FET measuring subroutine [Fetmeasure], Line 1820. Subroutine [Colrows], Line 3440, has been modified by replacing the section that entered the number of device columns and rows with a section to select a FET gate voltage, program lines 3730-4010. The selectable gate voltage steps are 0.1 V, 0.2 V, 0.3 V, 0.4 V, 0.5 V and 1 V. The selected gate voltage is placed in variable 'Vstep', and determines the number of data records required to store the measured values. Program variable 'Recs' is used to hold the number of data records.

Once the program has been started a variable called 'Pass' is given a default value of '0' (line 800) and the FET is measured using subroutine [Fetmeasure]. This measurement determines if the device passes or fails the default measurement criteria. If the device fails then the variable 'Pass' will continue to contain a '0' value and the program goes to [Finisprobing], Line 1630, where the program aborts back to the main (MENU) program file. If the device passes the standard Fet measurement the variable 'Pass' is given a '1' value and the program gives the operator a choice of aborting or continuing with the measurement. If the program is continued the program enters the detailed voltage current measurement routine [Startdetail], Line 1070.

At the start of the measurement routine [Startdetail] a data file is created on disc with the number of records stored in variable 'Recs' and of record length 112 real numbers. A loop is entered which steps the drain source volts from 0 V to +5 V in 0.1 V increments. For each increment in this loop power supply (715) is set to the loop voltage and the actual voltage and current are measured. DMM (716) measures the current and DMM (720) measures the voltage. The voltage and current values are stored sequentially in a variable array called 'V1' and a plot of the values is drawn on the monitor screen. On completion of the loop the data array is stored, the gate voltage is incremented by the amount stored in variable 'Vstep' and the measurement cycle repeated.

The measurement cycle is repeated until the program loops are completed or until the last three current readings of a measurement cycle are all less than 0.1 mA. The last three readings are held in variables 'V1(99)', 'V1(101)' and 'V1(103)' respectively. If the last three readings are less than 0.1 mA then the FET is defined as pinched off and the program leaves the measurement cycle and goes to a routine called [Pinchoff], Line 1510.

The routine [Pinchoff] fills all the remaining unmeasured records in the data file with a value of '-55' to signify null data. The data files are of the format shown below and are designated type 'V' data files.

FORMAT OF VOLTAGE/CURRENT CHARACTERISTIC DATA FILE:-
1st record:- RECS, VSTEP, RSLOPE, IDSSO, IGATE, GM, VPINCH, IDSS4,VKNEE, GD, SHORTLIM, VKNEELIM, RSLOPELIM, IDSSOLIM, GMLIM,

IDATELIM, VIDSLIM, VGATELIM, ------------------------------, -999
2nd record:-V_1, I_1, V_2, I_2, V_3, I_3, V_4, I_4, V_5, I_5 ------------- -------------, V_n, I_n, -999
3rd record to 'RECS' record, same format as the 2nd record.

Note:- Each record length is 112 real numbers. The first voltage and current readings in a record are the 0 V drain source values.

Modifications have been suggested to enable automatic device to device stepping to be added to this program. At the time of writing no further details of these mods are available.

viii) k10) DIODE FORWARD I/V CHARACTERISATION PROGRAM FILE (IDEALITY)

The hardware is configured as shown in figure (8).

DMM (720) ----- IEEE 720 SET TO AUTO RANGE
CURRENT SOURCE (719) ----- IEEE 719 SET TO 5 V VOLTAGE LIMIT
DEFAULT LIMITS ----- NONE

This program utilises the same general structure as the programs previously described. When softkey k1) is selected, the program requests that a current limit be selected, Line 560. Selectable current limits are 1 mA and 10 mA to 90 mA in 10 mA steps. Program lines 690 to 780 show that on current limit selection the variables 'Ilim' and 'Rangelim' are given values dependant on the limit selected. These variables are used in the main measurement subroutine [Idmeasure] to determine the range limit and current limit which stop the measurement cycle.

On entering the main probing loop, Line 1370, the program sets the current source to an output of +500E-6A. This current value is used to detect an open circuit condition. Program lines 1540, 1550 show that by interrogating the current source an open circuit can be detected. If an open circuit condition is detected the program enters a routine called [Opencir], Line 1620. This routine reverses the current source for an output of -500E-6A and rechecks if the open circuit criteria still exists, Line 1650. If the open circuit is confirmed the program stores a failure value of -1 in variable array 'CV (1)' and moves the prober table to the next device to be measured. If the open circuit is not confirmed then the current source polarity remains negative for the rest of the measurement

The voltage across the diode is read by a program function called [Measurevolt], Line 2380. If the measured voltage is less than 0.001 V then the failure value -2 is assigned to variable array 'CV(1)', ie a short circuit, and the prober table is moved to the next device to be measured. If the voltage is 0.001 V or greater then the program enters the main measurement subroutine called [Idmeasure], Line 2060.

Subroutine [Idmeasure] starts a loop that sets the current source ranges from 1E-9A to the range held by variable 'Rangelim', in steps of 1, corresponding to a decade range change of the current source. For each decade a second program loop is entered to step the current from unity to ten in steps of 1. A multiplying factor is applied to each step in this loop, line 2140, which equispaces the current values - when plotted on a log scale. The voltage is measured for each current step using function [Measurevolt] and the values stored in variable array 'CV (*)'. The measurement loop is halted when the loop reaches the value of variable 'Ilim' in the range set by variable 'Rangelim'. The data array 'CV (*)' is then stored on the data disc and the prober table is moved to the next device to repeat the measurement cycle.

FORMAT OF DIODE FORWARD I/V DATA FILE

1st record:- XCOL, YROW, ILIM, RANGELIM, XDEVN, YDEVN, XSTEP, YSTEP, XORIG, YORIG, ---, -999

2nd record:- I_1, V_1, I_2, V_2, I_3, V_3, ----- I_n, V_n, -999

3rd record to 'TDEV' record, same format as 2nd record

Note:- The length of each record is 192 real numbers.

ix) k9) MERCURY PROBE C/V PROFILE PROGRAM FILE (CVMANUAL)

This program file is identical to program file (CVPROBE) but does not include any commands to the autoprober table controller.

x) NON MEASUREMENT PROGRAMS

The remaining selections from the probing menu program are 'k7' view data disc directory, 'k6' prober setting up instructions and 'k14' erase all disc data. A brief description is given below.

k6) Prober setting up instructions:- This program called (INSTRUCT) graphically displays the prober setting up instructions. A selection available from this program calls another program called (PLANAR). This program (PLANAR) allows the operator to planarise the adjustable probes to the prober table. Power supply (713) is set to 5 V which is applied via Red LED's to each probe. The prober table is connected to the 0 V rail of power supply (713). The probes can then be planarised by adjusting the height setting screw at the rear of each probe until the associated red LED illuminates indicating an electrical contact between that probe tip and the prober table. This technique enables the probes to be planarised to within +-0.0005".

k7) View data disc directory:- The program is called (DIRECT) and displays the data disc directory. It is intended to modify this program in the near future so that individual data files can be erased from the data disc and the directory. The directory will then be compacted. A temporary option ie., 'k14' erases all disc data. This completely erases all data files from the data disc by initialising the disc.

6) CONCLUSIONS

The system described has been in regular use for the past 18 months. As a consequence of this extensive "field testing" various modifications have been made which have improved the ease of use of the system. The error trapping routines incorporated in the software have also been fully tested. It is noticeable that the autoprober is now frequently used in preference to the manual prober even for small numbers of devices. The data obtained has proved to be reliable and reproducible and the precision of the measurements is greatly improved when compared with the curve tracer/manual prober system previously used.

The measurement time of approximately 8 seconds per MESFET allows two large wafers to be fully measured during a working day with the added benefit that, once set up, the equipment will run unattended. It is estimated that 2 to 3 man weeks of intensive work would be required to carry out the same measurements on the manual prober. The ability to run the equipment overnight allows time consuming measurements such as C/V or diode I/V measurements to be made at a large number of sites on a wafer thus enabling the maximum amount of data to be gathered for device or process assessment.

The decision to use general measuring equipment based on the use of an IEEE-488 Standard Interface has proved a very flexible approach allowing improved measuring instruments to be easily incorporated into the system and providing potential for extending the range of measurements in the future. The use of 3.5" floppy discs for data storage has proved adequate so far but future requirements may necessitate the use of a data link to a large capacity storage disc accessible by both the measurement and data handling computers. The present arrangements, which requires the measured data to be converted from HP86 format to HP300 format before analysis, may be a limiting factor in any future expansion of the system.

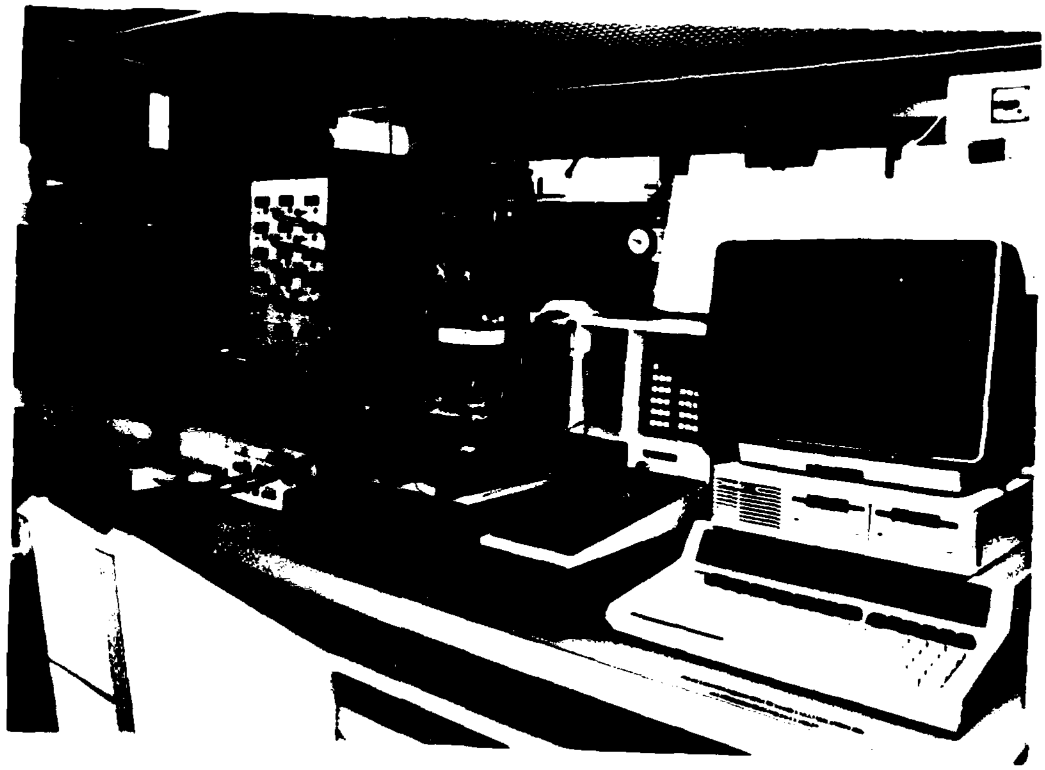


FIG 1. AUTO PROBER MEASUREMENT STATION

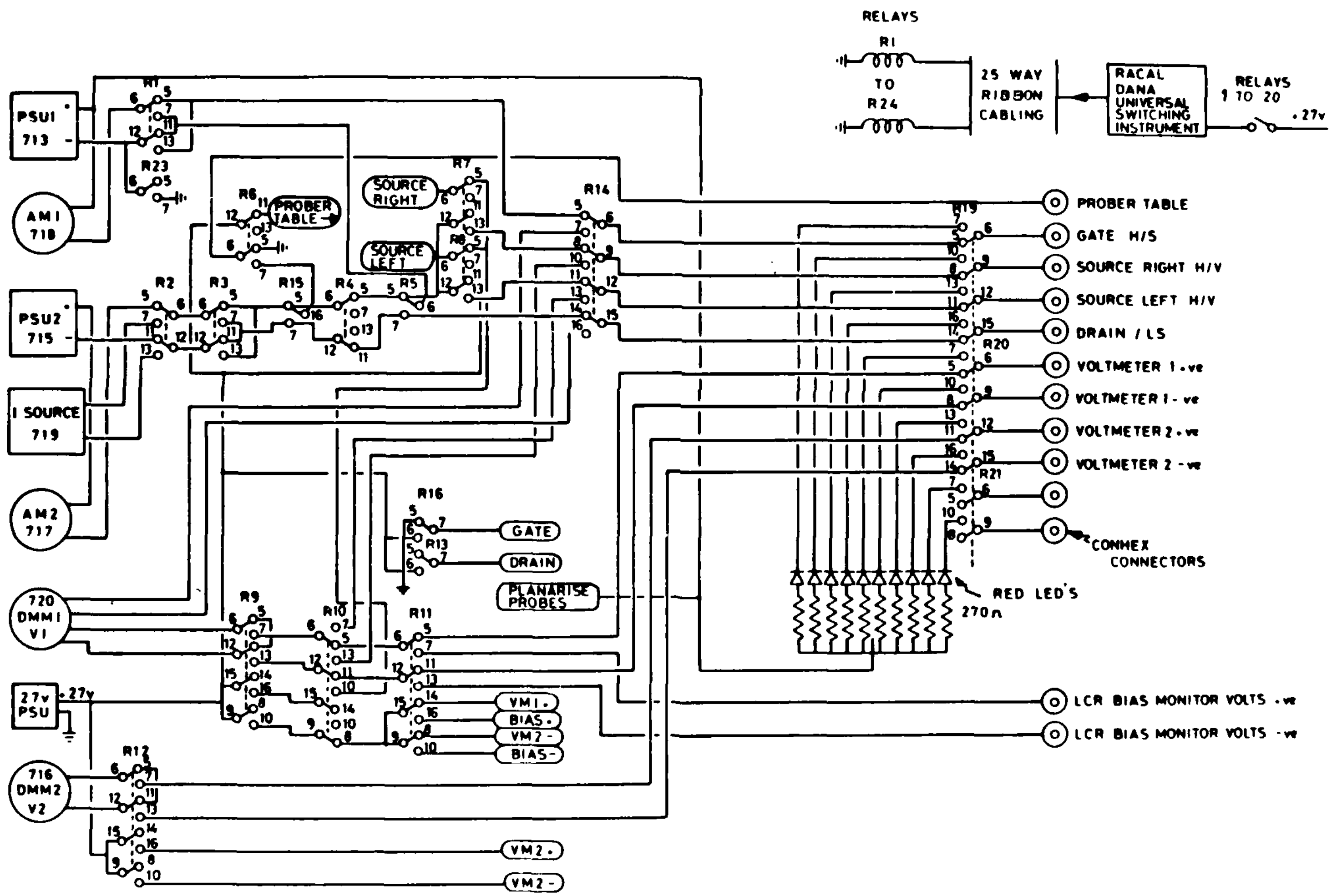
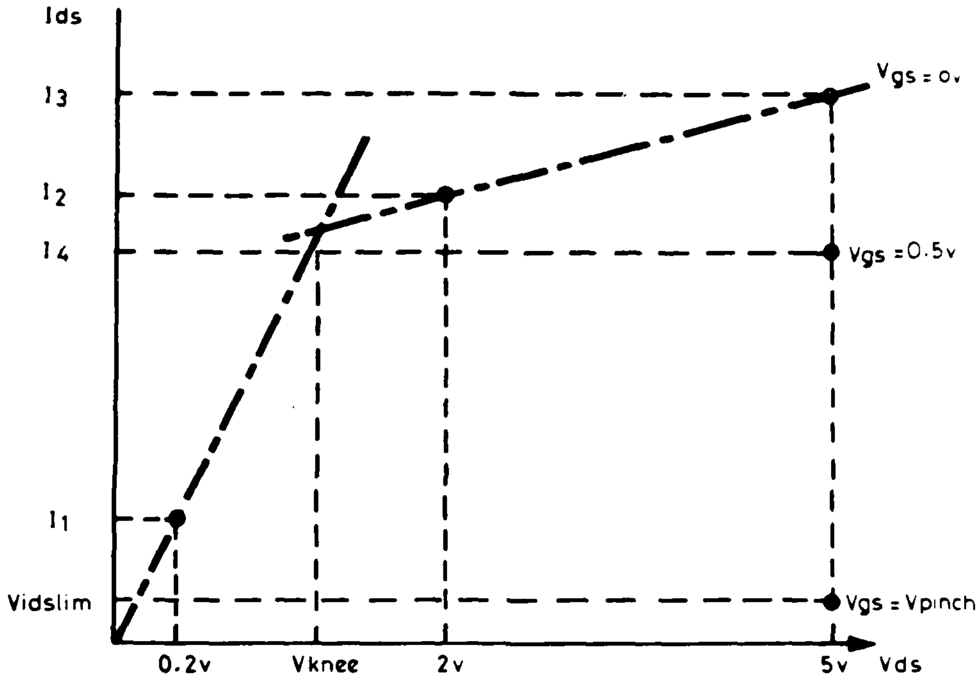


FIG 2 CIRCUIT DIAGRAM OF SYSTEM



$R_{slope} = \frac{0.2}{I_1}$: $G_d = \frac{(I_3 - I_2)}{5 - 2}$: $I_{dsso} = I_3$

$g_m = 2(I_3 - I_4)$

FIG.3. DEFINITION OF MEASURED FET PARAMERS

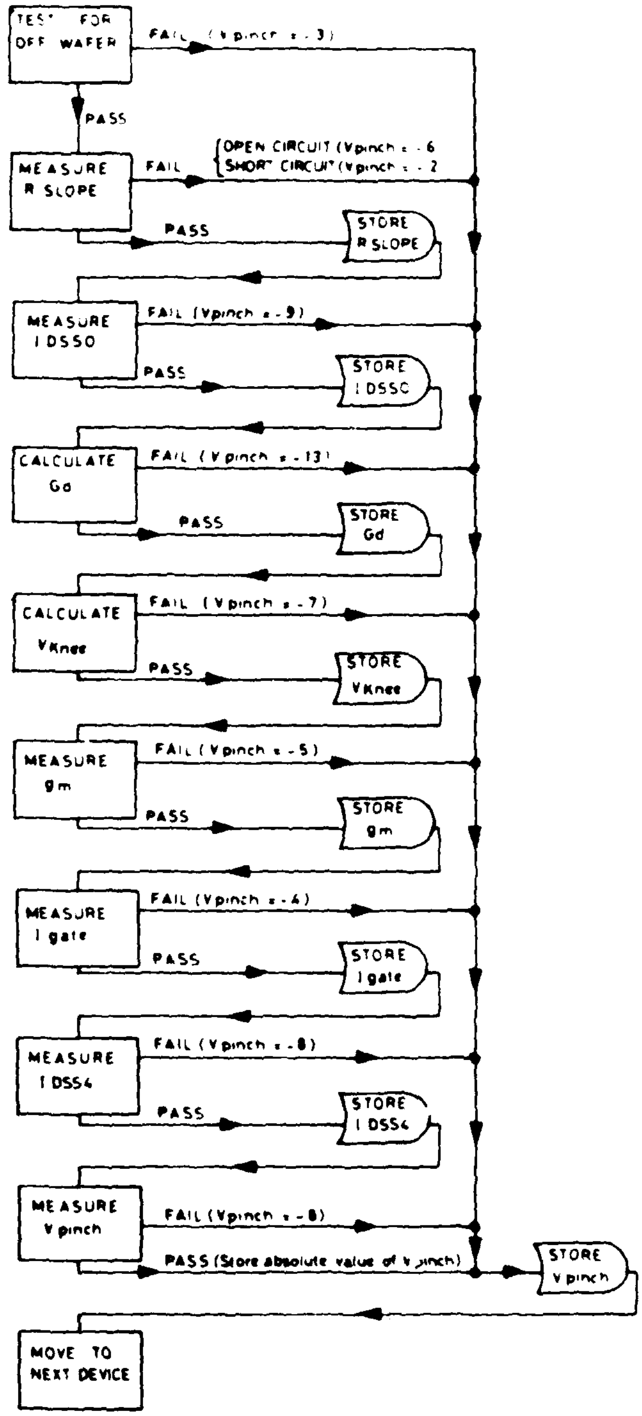
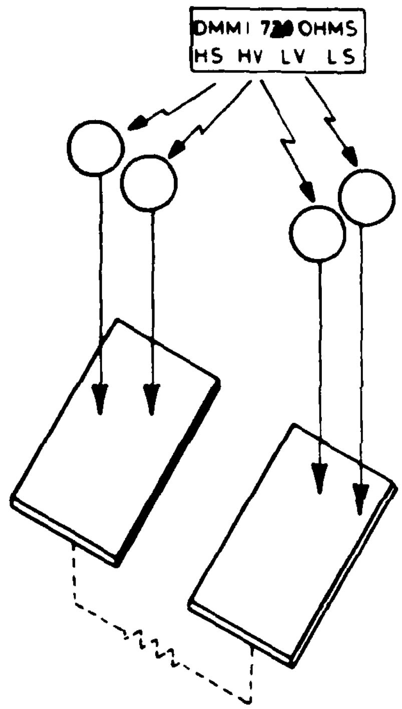
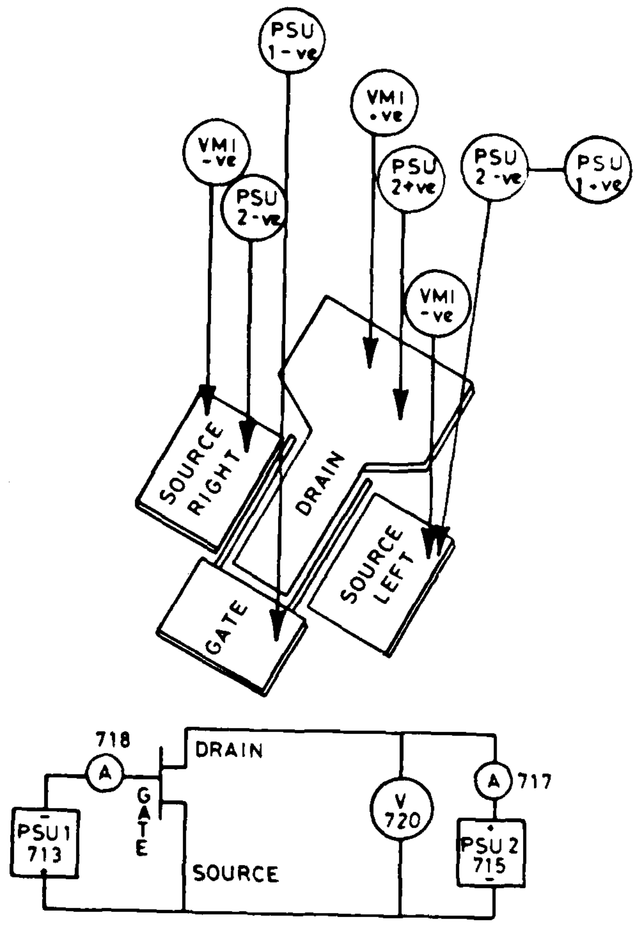


FIG 4 MEASUREMENT SEQUENCE



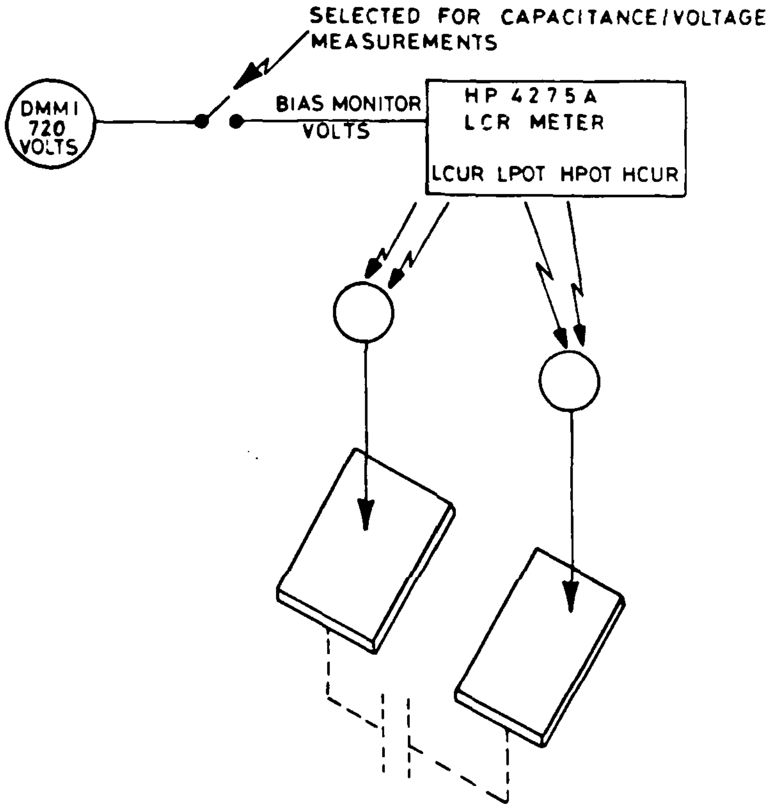
MEASURING CONFIGURATION SELECTED WITH RELAYS :-
R9, R10, R14, R13, R16.

FIG 5 OHMIC PROBING CONFIGURATION



MEASURING CONFIGURATION SELECTED WITH
RELAYS :- R1, R3, R7, R8, R9

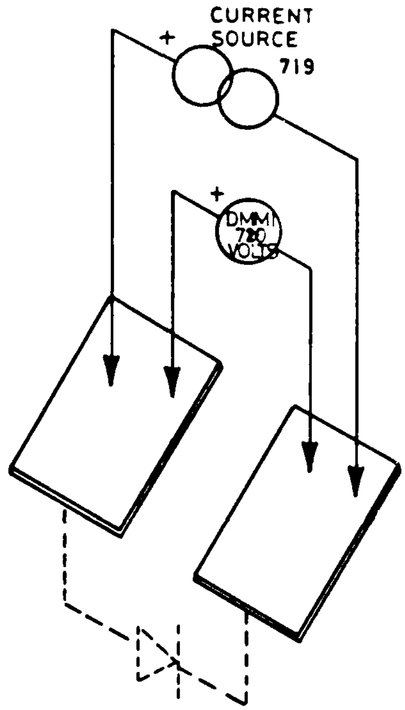
FIG 6 FET PROBING CONFIGURATION



FOR CAPACITANCE/ VOLTAGE MEASUREMENTS RELAYS R9, R11 ARE SELECTED.

FOR CAPACITANCE MEASUREMENTS ONLY NO RELAYS ARE USED

FIG 7. CAPACITANCE AND CAPACITANCE / VOLTAGE PROBING CONFIGURATION



MEASURING CONFIGURATION SELECTED WITH RELAYS :-
R2, R3, R8, R13, R9

FIG 8. DIODE I/V PROBING CONFIGURATION

DOCUMENT CONTROL SHEET

Overall security classification of sheet ...........UNCLASSIFIED...........

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1. DRIC Reference (if known)	2. Originator's Reference MEMO 4065	3. Agency Reference	4. Report Security Classification
5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location RSRE, St Andrews Road, Malvern, Worcs. WR14 3PS		
5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location		

7. Title AUTOMATIC PROBER FOR THE DC CHARACTERISATION OF GALLIUM ARSENIDE DEVICES - PART 1 THE MEASUREMENT FACILITY.

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers) Title, place and date of conference

8. Author 1 Surname, initials	9(a) Author 2	9(b) Authors 3,4...	10. Date	pp. ref
HUGHES, B.T.	AVERY, B.E.		1987 July	36

11. Contract Number	12. Period	13. Project	14. Other Reference

15. Distribution statement

Descriptors (or keywords)

continue on separate piece of paper

Abstract A computer controlled Auto Prober System has been designed and constructed to allow detailed information to be obtained from the large number of Gallium Arsenide (GaAs) devices fabricated in the Microwave Devices Division (DP2). GaAs substrates up to 2 inch diameter can be processed in the DP2 clean room and typical substrates may contain several thousand devices and test patterns. The prober system consists of two separate facilities, one to carry out the DC measurements and the other to allow the data obtained to be analysed and correlated.

This memo describes the measurement facility and gives details of the DC conditions under which the measurements are carried out. A full description of the software is included in this memo and a listing of the software is given in a separate appendix. The data analysis facility is described in RSRE Memo 4066.

S80/48

Contd on separate sheet

Abstract (cont'd)

- Both facilities have been designed as an integrated system and offer a range of on wafer measurements which include characterisation of active devices such as GaAs MESFETs (MEtal-Semiconductor Field Effect Transistors) and Schottky diodes as well as measurement routines for use on various test patterns for assessing ohmic contacts and investigating doping profiles of device layers. Passive components such as on wafer capacitors and resistors can be measured.

The system is designed for non-expert use and emphasis has been placed on providing standar measurement routines which can be easily selected from screen menus. Wherever possible flexibility and error trapping have been built into the system.

END

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